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Applying the Precaution Adoption Process Model to the Acceptance of Mine Safety and Health Technologies

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Abstract

Mineworkers are continually introduced to protective technologies on the job. Yet, their perceptions toward the technologies are often not addressed until they are actively trying to use them, which may halt safe technology adoption and associated work practices. This study explored management and worker perspectives toward three technologies to forecast adoption and behavioral intention on the job. Interviews and focus groups were conducted with 21 mineworkers and 19 mine managers to determine the adoption process stage algorithm for workers and managers, including perceived barriers to using new safety and health technologies. Differences between workers and managers were revealed in terms of readiness, perceptions, and initial trust in using technologies. Workers, whether they had or had not used a particular technology, still had negative perceptions toward its use in the initial introduction and integration at their mine site, indicating a lengthy time period needed for full adoption. The key finding from these results is that a carefully considered and extended introduction of technology for workers in Stage 3 (undecided to act) is most important to promote progression to Stage 5 (decided to act) and to avoid Stage 4 (decided not to act). In response, organizational management may need to account for workers' particular stage algorithm, using the Precaution Adoption Process Model, to understand how to tailor messages about protective technologies, administer skill-based trainings and interventions that raise awareness and knowledge, and ultimately encourage safe adoption of associated work practices.

Keywords

Mine health and safety; Precaution adoption process model; Protective technology; Qualitative methods; Risk communication; Risk perception

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Technology and associated safety and health practices within the mining industry have improved via research and support from government legislation (Glover and Morse 2000). Specifically, the US Congress passed the Mine Improvement and New Emergency Response Act of 2006 (MINER Act), which provides funding to encourage the research and development of new technologies (Gurtunca 2008; MSHA 2006). As a result, technologies continue to move forward, likely contributing to decreased accident rates in mines and

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improved, tangible tools that miners need to maintain personal safety and health (Nieto and Duersken 2008).

However, when introducing technology as a tool for enhanced safety and health (S&H), its conscious integration within a risk management framework is often absent, perhaps due to the inherent risks perceived among new end users (Sjöberg 2002). Hebblewhite (2009) argues that communication, education, and training around a risk-based management strategy are needed to adequately incorporate technology on the job. Similarly, mining experts discuss the need to complement technological advancements with a focus on human elements, including worker surveys, trainings, incentive programs, and opportunities for feedback and engagement in decision making (Langton 1995; Peters 1995; Peters et al. 1997; Weyman et al. 2003). Despite such recommendations, technological and human factors integrations have not progressed to their full potential to proactively improve behaviors and reduce workers' risks.

This study explored, by way of several mine S&H devices, management and worker perspectives that forecast technology adoption. This paper used a well-established health promotion theory – the Precaution Adoption Process Model [PAPM] (Weinstein 1988) – to characterize technology adoption, behavioral intention, and practices associated with their use in the mining environment. These topics were explored during interviews and focus groups with miners and mine management. Before discussing the protective S&H technologies and study design at hand, an overview of typical working conditions in mining is provided to give context to the many contingencies and requirements that exist in this dynamic environment.

An Overview of Safety and Health Burdens in Mining

The mining industry remains an important part of economies both domestically and internationally. Regardless of whether the commodity – which could be coal, metals, minerals, etc. – is extracted on the surface or underground, the working conditions are consistently acknowledged as physically demanding and workers are exposed to countless risks (Phakathi 2017). Data from the Mine Safety and Health Administration (MSHA 2017) suggests that citations and recordable injuries are most often related to slip, trip, and fall hazards. Also, mining equipment, like the continuous mining machine weighing up to 100,000 pounds, presents additional hazards to be aware of on the job. This equipment contains several moving pieces such as rotating drums to cut the product, as well as conveying systems to load the product into a shuttle car for transport. Even if specific workers do not operate such equipment, however, they still have to be aware of all of the moving pieces, parts, and tasks that occur around them in an environment with roof heights that range anywhere from 3 to 11 ft (MSHA 2009). Simply put, when National Public Radio [NPR] interviewed miners to better understand their work environment, miners stated the work is "dark, dirty and dangerous." (2007).

In both underground and surface mining, miners are exposed to ongoing risks including but not limited to extreme high-low temperatures with humidity present, contaminant exposure such as respirable dust, diesel, and noise, as well as long work hours and rotating shifts

(Kurmis and Apps 2007; Salas et al. 2015; World Health Organization 2007). More specifically, a NIOSH (2010) analysis of the National Health Interview Survey [NHIS] data for the mining, oil, and gas population showed the following for this occupational group: 50% of miners work more than 48 h per week; 42.4% of them work non-standard shifts; 66.8% experience prevalent exposure to vapors, gas, dust, or fumes; and 20.6% report a prevalence of work-family imbalance.

Due the numerous hazards described above, negative health outcomes are all too common for miners – especially toward the end of their careers. To illustrate, a NIOSH (2012) analysis of NHIS data collected from the mining sector during 1997–2007 showed that approximately 23% of miners had functional limitations and 22% had hearing difficulties. This same data set also revealed that 43.9% of miners over the age of 65 required some type of surgery in the last 12 months. In addition to these negative health effects, 54.8% of miners reported high levels of job insecurity in recent years (NIOSH 2010) which can have its own consequences on physical and mental health.

Although not all of these S&H outcomes can be mitigated through the development and use of technology, mining and affiliated research industries have come a long way in developing protective technologies for the benefit of the workforce. However, whenever one technological solution is offered, it often introduces other unintended hazards that were not considered (Vaught et al. 1999). For example, miners typically have to wear a belt that holds their tools, monitoring devices, and a self-contained self-rescuer in case of an emergency. With all of these tools and devices adding weight around a miners' waist, it is necessary to address many aspects of protective technologies that miners may encounter during their shift, and the tradeoffs that miners perceive for health, safety, production, and quality of their work. This study used a stage change model to examine these tradeoffs using three recent S&H technologies to help identify and improve how organizations can prepare their workforce for these imminent changes.

Protective S&H Technologies

Protective technologies are used to provide identification and defense from work hazards (OSHA 2002; NIOSH 2007). For end users to safely adopt and use technologies, however, it is critical for them to understand how the technology can improve individual and organizational health (Wahlström 1992). To demonstrate, previous studies indicate that initial trust in consumer-based technology may affect individuals' readiness to adopt the technology, their risk perception, and subsequent behavior (McKnight et al. 2011; Siegrist 2000; Siegrist 1999). This information is critical to know in high-risk industries such as mining in order to identify at-risk attitudes and help mitigate potential incidents. This paper reports on the initial adoption of and behavioral response to three protective technologies intended to help prevent workplace incidents.

Theoretical Lens to Study Technology Acceptance in Mining

Although frameworks have been used to understand how technologies are interpreted by consumers (Davis 1989), technology adoption in occupational sectors has been studied less from a theoretical perspective (Chenoweth et al. 2009). Stages of change models treat behavior change as an active process, noting that messages and interventions should match the specific stage that an individual is at in his or her behavioral progression (de Vet et al. 2008). The *Precaution Adoption Process Model* (PAPM) is a stage model developed to explain precautious behaviors to avoid external hazards or health threats (Weinstein and Sandman 1992; de Vet et al. 2008). The PAPM contains seven stages ranging from being unaware of a particular hazard to maintenance of a behavior to mitigate risks (Table 1).

Based on these stages, if an individual decides not to act, then adoption of the technology or intended behavior does not or takes a long time to occur. Weinstein et al. (2008) suggest using these stages as a framework to help "fill in" individuals' process of behavior change. Because previous studies (e.g., Blalock et al. 1996; Sniehotta et al. 2005; Wammes et al. 2005; Costanza et al. 2005) have shown that differences exist in individuals' risk perception depending on their current PAPM stage, understanding the stages of change among miners and managers was of interest for the current study.

Research Questions

In a constantly changing environment, understanding the role(s) that new technology may have on workers' overall awareness and behavior is critical for safe decision making. Additionally, with significant resources being put into the development of new technologies, it is important to recognize the nuances associated with such innovations in the mining industry. In response, this study sought to understand the following research questions:

- By way of using the PAPM to assess stages of change, what is the (1) stage algorithm acceptance and (2) behavioral intention of using various mine S&H technologies *by mineworkers?*
- By way of using the PAPM to assess stages of change, what is the (1) stage algorithm acceptance and (2) behavioral intention of using various mine S&H technologies *by mine managers?*

Methods and Materials

Several research studies were designed as part of an overall objective to obtain information from miners and mine management about their risk vulnerability toward various S&H hazards and subsequent use of S&H technologies to reduce these worksite risks. This paper reports on some of the information collected as a part of these studies. Interviews and focus groups were used to account for participants' personal experiences and observations, and to understand multiple viewpoints (Kvale 2008). Human subjects research approval was obtained before the workers and managers at respective sites were recruited through convenience and snowball sampling approaches (Miles and Huberman 1994).

Data Collection with Mineworkers

Health and safety managers were contacted via e-mail/phone and the purpose of the respective studies was explained to them. Five of these individuals presented the information to their employees and two helped recruit workers from other locations. As a result, 21 mineworkers from seven mines were interviewed between January and September 2014.

Nine mineworkers from five underground coal mines and 12 workers from two surface industrial mineral mines participated. The participating mineworkers were not paid for their participation. Rather, they were given permission by a supervisor to participate on the clock during normal working hours. Interviews took place on the mine site or at a nearby mine training center. Prior to each interview using an approved IRB protocol, all workers were provided an informed consent document that detailed the purpose of the study and contact information should they have any follow-up questions.

All of the participants had experience in a variety of positions (e.g., roof bolter, scoop operator, shuttle car/haul truck driver, bulk loader) ranging from 3 to 37 years (M = 19.4 years). Interviews lasted from 20 to 60 min. Experience of participants varied but similarities across their risk knowledge, attitudes, and behaviors quickly emerged, reaching saturation of data by the end of recruitment at the participating mines (Corbin and Strauss 2008). Although opinions vary, anywhere from 6 to 12 individual participants are common for interview data collection procedures (Johnson and Christensen 2017; Kvale 2008).

Data Collection with S&H Managers

Mine S&H managers are responsible for acclimating workers to new technologies and also have to use technologies to fulfill regulatory S&H obligations. Therefore, it was necessary to investigate how managers perceive and use technology-related devices with their workforce. Corporate health, safety, and environmental managers allowed researchers to facilitate two focus groups as a part of a continuing education workshop that was organized by the Nevada Mining Association and occurred in June 2015. This 8-h workshop was provided by NIOSH and managers who chose to attend received continuing education credits. As a part of the workshop, a two-series segment occurred with participating managers throughout the day. The first segment included the 45-min focus groups discussed within this paper. The purpose of this first segment was to understand managers' perceptions and attitudes toward new S&H technologies in mining, their experiences with these technologies, and how NIOSH could help minimize barriers to using technology. The second segment included an overview and hands-on practice using the technologies and associated software discussed within this paper. This two-part segment occurred once in the morning and once in the afternoon, resulting in two focus groups. The workshop itself included several large mine corporations and ultimately garnered 19 participants. Each focus group lasted approximately 45 min. All participating individuals were safety and health managers, mine managers, or industrial hygienists who dealt with protective technologies as a part of their job responsibilities at their local mine. Prior to each interview using an approved IRB protocol, all managers were provided an informed consent document that detailed the purpose of the study and contact information should they have any follow-up questions.

Data Collection Instruments

An interview guide was developed to question individual mineworkers and questions were slightly modified to inquire during the focus groups with managers. This paper focused on the initial acceptance and outcomes when S&H technologies are introduced and used. To better assist in understanding the nuances of each technology probed during interviews and focus groups, Table 2 highlights the three specific technologies, their end users, and potential implications.

As Table 2 demonstrates, the technologies all provide some level of protection for workers in terms of proactively identifying S&H hazards such as being fatally injured or overexposed to respirable contaminants. Additionally, all of these technologies provide some type of audible alert or visual output that served as a cue for workers to take action (e.g. move to a different location, change a work practice) or management to take action (e.g. secure new engineering controls to protect workers).

The first portion of the script was framed to categorize current stage acceptance of S&H technology (Weinstein and Sandman 1992; Janz and Becker 1984). Weinstein and Sandman (1992) developed a single measure to assess the stage algorithm, or willingness, of an individual to accept or modify a behavior. This quantitative measure was adapted into a qualitative probe (Table 3) to assess each participant's PAPM algorithm stage pertaining to the respective S&H technology. Because the PAPM scales were adapted for open-ended discussion to understand perspectives around specific technologies, the initial part of the interviews and focus groups were more structured (Corbin and Strauss 2015).

Each individual participant was probed to respond to one technology that they were currently or had used on the job for this structured portion of the interview while managers in focus groups discussed more than one technology, depending on their experience and knowledge of the technology. Even though managers were aware of all of the technologies referenced, they were asked to reference one during the focus group in which they had actual hands-on experience in order to better understand their progression through the PAPM stages. Overall, the technologies were evenly distributed among participants to allow for a breadth of responses and to garner varying opinions and experiences. Again, the purpose of including a variety of technologies in one study was to determine trends in miners' perceptions and adoptions of S&H technology and associated changes.

Subsequently, potential barriers to accepting and using the technology to reduce worksite risks were discussed. The Health Belief Model [HBM] (Janz and Becker 1984) informed these follow-up questions to help understand participants' rationale for their particular stage algorithm in the PAPM including their perception of risk on the job, hazard identification, and mitigation strategies. Examples of questions and prompts included:

- What are some cues that alert you of various workplace hazards?
- What are some things that you do to minimize these hazards?
- How will adding [technology] change the risks you/the organization encounter on the job?
- Tell me about some of your experiences with [technology].

All information was captured via detailed note-taking. Upon reviewing the notes with the 21 mineworkers and 19 managers who participated, researchers were sufficiently comfortable with the breadth and depth of data collected to answer the research questions that were posed for this study. At this point, saturation of content was deemed appropriate and recruitment ended (Corbin and Strauss 2008).

Data Analysis

The primary analysis was undertaken by the researcher who conducted the interviews and focus groups while two additional researchers assisted with note-taking and organizational and initial coding of open-ended data. This study demonstrated new use of the PAPM. Historically, the stage algorithm is used to collect quantitative information from target individuals (e.g. Blalock et al. 1996; de Vet et al. 2008; Weinstein and Sandman 1992). This study utilized the same scale in a qualitative setting to gain detailed feedback from participants to understand their rationale during each stage of the PAPM.

The data were analyzed using a content analysis approach for each PAPM algorithm scale (Krippendorff 2012). The follow-up questions that were open-ended were thematically analyzed using the constant comparison method with an emphasis on theoretical coding efforts (Glaser and Strauss 1967; Boyatzis 1998). Constant comparison was used to compare varying sections, or incidents, of data for similarities and differences among the data sets (Glaser and Strauss 1967). Incidents that were found to be conceptually similar were grouped together and linked in a way that could inform technology acceptance and adoption within and between these two organizational groups – workers and managers – with the emphasis on determining perceived barriers and potential solutions for those workers who have to integrate the technology into their jobs.

Results

Each participant had heard of the technologies discussed during the interviews and focus groups (i.e., Stage 2). Additionally, with the exception of one manager and two individual miners, all participants had thought about the technologies and the potential implications their integration could have on their work environment. In relation to the actual adoption and use of the technologies, however, individual workers and managers differed in their perceptions and behaviors (Table 4). Table 4 shows the overall breakdown by stage for the specific technology in question from participants. Due to the small sample size, a breakdown by technology is not provided. Rather the overall responses provide insights that can be gleaned about technology adoption and progression through the PAPM stages. However, because participants were recruited who had varying levels of experience and familiarity with the technologies in question, the breakdown across technologies tended to be similar.

Participant Adoption of Technology

Workers had varying perceptions and adoption intentions toward the technologies discussed. As Table 4 shows, seven workers were undecided about the technology in question; nine determined they did not want to use the technology as a part of their job; and five decided they did want to use the technology. These responses are vastly different from those of the managers, where one was undecided about the technology and the remaining 17 already decided that they wanted to use the technology as a part of their job. The discussion uses the open-ended data to shed information into these PAPM stage algorithms collected at the onset of the interviews/focus groups.

Stage 3: Hesitation toward S&H technology

Many participants were still experiencing growing pains with the technology in question, regardless of the technology they were discussing. Basically, whenever anything "new" is introduced to their workforce, managers discussed their employees' initial resistance prior to becoming familiar with the nuances of the system. One-third of workers were undecided about the S&H technology, with one manager being undecided as well. Out of these individuals, half had used the technology in question and half had not. For those who had used the technology and were still unsure, they had around 3–6 months of user experience. These workers expressed their frustrations with the various systems not working, failing mid-task, not ever seeing the results of using the technology, and slowing production. For example, one unsure worker who had been using a safety technology said, "Anything manmade has the opportunity to fail – this just has too many bugs and we need more information." Another worker who had not used the technology yet but heard stories about it said, "This technology is bound to fail and will only be as good as the person operating it."

These statements indicate a lack of trust in the technology due to previous experience with error or experiences heard second-hand through other users. Similar apprehension existed in the undecided manager, who said, "The software should do the work…I should be able to open it and it runs without issue." Due to the unreliability of these tools, participants were hesitant toward fully embracing these technologies as a part of their job.

Stage 4: Rejection of S&H technology

While no managers said they did not want to use the S&H technology in question, almost half of the workers who participated were against using them. It is not surprising that fewer managers rejected S&H technology, since they are not the ones wearing it for up to an entire work shift while trying to complete their job. Six of these workers had experience using the technology and three had not. The three workers who had not used the technology but already decided against it referenced countless "horror" stories they had heard from workers at other mine locations. For example, one worker was against a technology because "Other people have said it's not working. It will have to get all the bugs worked out in the system before I will use it." Another worker said, "Everyone that I have talked to, which includes electricians and operators, have said that it's a mess…and troubleshooting it is a pain I guess." These responses show the impact of negative communication about technology, instilling a resistant perception toward its use. Some workers also indicated that using the technology is "just one more thing" that they have to do on the job and although it may be beneficial from a S&H standpoint, it is still inconvenient.

Workers who had used the technology and decided against it had operating experience from 6 months to 1 year. They expressed concerns for their personal safety and health on the job, referencing technology malfunctions or inaccuracies in the data. It was common for participants to say that the technology had too many faults or did not work all the time, making it too difficult to put their trust in the data. One worker said, "Basically, everything we work with interferes with it." Another consistent trend in the responses was a reference to the technology "breaking up my routine," and being "mentally taxing." The idea of the technology adding to the unpredictability of their job, including changes in job tasks and production, was stressful for workers. Those workers who experienced several problems with the technology were the most apprehensive and anticipated they would have difficulty fully adjusting to the technology. Finally, a frustrating aspect of these technologies was the simple fact that changing mine conditions contributed to workers' uncertainty in being able to function and predict hazards – making trends per mine site difficult for the workforce to identify. Common examples revolved around encountering a new part of the mine or different environmental conditions, meaning that the hazards detected by the technology could change. So, it took longer than anticipated for workers to be able to proactively identify and mitigate possible alerts from the technology.

It is worth noting that, although all three of the technologies rendered rejection by participants, the regulated technology (i.e. proximity detection systems) was predominately rejected more often than the other two technologies that were not regulated. This is not surprising given the technology is regulated and required on site. Therefore, workers are using the technology more and therefore, experiencing more glitches and interference with job demands while adapting to the technology. In addition, this regulated technology is a permanent part of their job demands, not just a temporary assessment.

Stage 5: Acceptance of S&H Technology

Participants who wanted to use the technology in question were already actively using it and therefore knew and appreciated the benefits that the technology could offer. For example, one worker said, "It shows your bad habits" while another said, "I learned what I shouldn't be doing but was." This feedback illustrates that workers appreciated learning and knowing exactly what they were doing that was risky, and how to fix their behavior. Similarly, one worker said, "I can control things better and make things safer for other people."

Managers who wanted to use the technology shared similar views. However, they were more focused on how the technology could make their jobs easier rather than safer because they are responsible for maintaining the safety and health rules and regulations on site. For instance, respirable dust sampling can be required by MSHA at any point in time throughout the year. Often, mines collect their own samples to mitigate potential dust sources on site prior to an MSHA visit. Regarding the use of both the Helmet-CAM and end of shift silica technology, one manager was more enthusiastic because of the time these technologies would save him. Specifically, the manager indicated that, due to being able to see results of a sample post-shift rather than waiting several weeks, he would be able to conduct more samples in areas that were deemed "low priority" for the mine, meaning areas where respirable dust may not be as much of a problem, but could still use reduction strategies. This sentiment of additional health and safety attention across the mine site was shared among a majority of managers who participated in the discussions.

Both managers and workers shared their relief that technologies were in more advanced stages than when first introduced on their site. One worker said, "It helps that the bugs are finally worked out." Similarly, a manager noted that he would use the technology more if additional kinks were worked out in the system while others commented that one would be more applicable after it became user friendly. Ultimately, however, participants said that, once overcoming initial bugs or barriers, the technology was beneficial and they know the intention of the technology is to protect them on the job. To illustrate, one worker said, “Everyone hates change at first, but this is a good thing, I think we can all agree on that.” The individuals who had embraced the technology and wanted to use it had already been using the technology on the job for approximately 1.5 to 3 years. This finding is useful when looking specifically at the 16 workers (out of the 21 interviewed) who at experience using the technologies in question. Their current stage of the PAPM and their experience with the technology, in years, is plotted in Fig. 1 below (those who had not used the technology could not be plotted). In addition, because all managers who reported using the technologies only reported doing so in terms of testing the technology and not using it as a part of their job, they are not plotted on the scatter plot (although if they were almost all responses would be on the top right of the plot).

Discussion

Overall, these results provide useful information when considering how to best introduce and integrate new devices within a mine’s risk management system. The PAPM stage classification afforded the opportunity to not only assess the distribution of stages within the target population at a particular point in time, but also to inform potential designs of individual and organizational-level interventions (Weinstein et al. 2008) to help workers in particular, move through the PAPM stages. Implications for these results, by specific stages, are discussed below.

Responding to Differences in Workers’ Stage Algorithms

First, it is important to note that there are stark differences between hourly miners’ and managers’ willingness to accept and use new technology. The results show managers are more likely to accept and adopt technologies quicker and use with more ease than miners. This finding is not particularly surprising because, in most cases, miners are the end users of technologies who must continuously use them whereas managers ultimately communicate about, train, and perhaps use technology to assess rather than complete a job. However, it is necessary for management within organizations to understand that their workforce is likely to be much more reluctant than they are toward technology changes and what they can do to help during transitional phases. This information lends itself to various considerations about the best ways to communicate and train miners to better manage risks on the job as new devices are being added to their personal work belt or equipment.

Specifically, if the PAPM stage for individuals should match the interventions targeting them (Weinstein et al. 2008), then organizations will have to take into account the vastly different perceptions that their employees may have toward something new or something they have been hearing about (perhaps in a negative way) for quite some time. In response, leadership may need to spend more time initially communicating about the benefits of the technology, including skill-based training to improve user efficacy, while also providing realistic expectations that it could take time to consistently function as intended.

Of importance, the results also illustrate that for miners who were undecided or against using various technologies, their hands-on experience with the equipment was limited to, on average, six months to one year. Alternatively, those who decided they wanted to use the technology had been using it for closer to two years, illustrating the lengthy adoption process of something "new" on the job. Also, miners who had fully adopted the technology said, "If you would have asked me a year ago I would have said no way will I ever be able to use this." Understanding potential malfunctions and perceived risks among mineworkers could help troubleshoot aspects of their adoption processes. In other words, knowing if a miner is in Stage 3 (i.e. undecided toward using the technology) is critical to help prevent them from moving into Stage 4 (i.e. no) and rather, being accepting of and adopting a new sense of situational awareness with the technology in place. Similarly, knowing if a miner is in Stage 5 (i.e. decided to adopt technology) is important for the organization to know so they can remove any situational obstacles that may be present in advancing to Stages 6 and 7 of full acceptance and use (Weinstein 1988). Intervention and training ideas in addition to complementary communication messaging, in relation to Stages 3, 4, and 5 of the PAPM are described herein. Considerations focus specifically on ways to understand and engage the workers since they are the ones who ultimately use a majority of new technologies.

Intervening at Stage 3

Of the 21 workers who participated, 7 were unsure of whether or not they wanted to use the technology; three miners had used the technology and four had not. This stage of the PAPM is one where technology use does not seem to impact perceptions and intentions as much as the subsequent stages. However, research has shown that perceptions of personal vulnerability or susceptibility (Shepperd et al. 2013) are crucial in determining whether an individual decides to take action (Weinstein et al. 2008). In other words, if miners feel personally susceptible to the risk or hazard the technology is trying to protect against (e.g., being pinned by equipment or expose to high amounts of respirable dust) they are more likely to adopt the mechanism in place to protect them.

However, when asked about the risks associated with their job, including exposure to respirable dust as well as being pinned by equipment, most miners responded feeling little vulnerability to these hazards (for detailed results of these different analyses of the data see Haas and Rost 2015; Haas and Cecala 2015). Specifically, feedback from participants supported that perceived vulnerability toward experiencing a safety or health incident predicted an increase of miners' behavioral intention to use the technology. These results were consistent with previous studies that show technology acceptance is correlated with personal risk perceptions (e.g., Fukuyama 1995; Weinstein 1989, 1999).

In response, if organizational leadership takes the time to initially investigate the perceived vulnerability of their individual miners and determines that perceived vulnerability is minimal, then interventions and training about the risks associated with S&H hazards may be needed to help move workers into precautionary action. Although studies have detailed miners' high threshold for risk and unrealistic sense of optimism on the job for quite some time (Haas and Rost 2015; Peters and Wiehagen 1988), it is apparent that advances are needed to help this population realize and accept certain risks so they are more willing to engage and adopt self-protective technologies and associated behaviors.

Health education scholars suggest the value in making each individual person's risks clear by comparing an absolute and normative standard, using undeniable outcomes of the risky choices (Eldredge et al. 2016). Research has investigated these issues for both occupational risks (e.g., Haas et al. 2016; Haas and Mattson 2016; Peters et al. 2007) and risks encountered through recreational hobbies such as bicycling or motorcycling (e.g., Fernandes et al. 2007; Haas and Mattson 2015). These results demonstrated that more in-depth information about the statistics related to localized S&H risks prompted a change in perceived vulnerability. In other words, making the consequences seem more normative rather than allowing individuals to compare themselves to everyone else, assuming they take less risks than others, has a significant impact on precaution effectiveness.

Of importance, results of this study highlight the uniqueness of the PAPM in being able to use Stage 3 as an intervention point with undecided or even uninformed miners. One of the technologies in question within this paper, the Helmet-CAM, could be a viable intervention tool to use with miners who are in Stage 3 of the PAPM and also feel somewhat invincible to experiencing incidents on the job. Previous intervention studies have used the Helmet-CAM to help miners and mine management identify unknown sources of respirable dust over a period of time (Haas and Cecala 2017). Prior to using the technology, several workers mentioned feeling pretty well protected from respirable dust exposure and their chances of being diagnosed with a respiratory disease as minimal (Haas et al. 2016).

However, interventions at five separate mine sites showed significant changes in miners' proactive behaviors after visually seeing the dust they are exposed to on the job (Haas and Cecala 2017). Therefore, for any sort of contaminant type of exposure that can be measured such as dust, diesel, or noise, this technology can actually be used as an intervention to move workers from Stage 3 to Stage 5. Still, research has shown that communication about risks with people of significance, such as a manager or mentor, is a critical factor in moving from Stage 3 to either 4 or 5 (Eldredge et al. 2016). Therefore, if assessment technology is not available at a work site, any type of leader realistically engaging workers in the probability of incidents related to occupational risks is still likely to be a worthwhile activity.

Fear appeals have also been studied as a communication method to promote personal health behaviors. Although this can be a quick and easy go-to method on the job, research has found that fear arousal is not as important in motivating precautionary action as perceiving the mechanism or behavior as being effective (Ruiter et al. 2001). Rather, focusing on the probability of occurrence in a more disassociated sense, such as reviewing the respiratory disease diagnose statistics or injuries resulting from a specific hazard, to including fatalgrams that are posted on MSHA's website, could help miners localize risks to their job tasks.

Regardless of delivery mechanisms and messages used to encourage a mindset of constant awareness rather than complacency, it is important to assess changes in individual risk perceptions before and after such discussions or trainings (Haas and Mattson 2016). In addition, after knowing if and to what degree an individual feels susceptible to specific safety and health hazards, it is possible to further examine what factors are contributing to these attitudes. If external factors are identified as shaping miners' perceptions, this can also provide insights into changes worksites can make to better communicate and share information to employees who have not yet formed an opinion. Hopefully these efforts transition workers into Stage 5.

Intervening at Stage 5

If individuals, such as those four miners who reported adopting and acting on the technologies they were discussing, progress to Stage 5, then skills-based training to identify user barriers and improve self-efficacy are most critical. For example, one study that focused on regulating driving behavior among older populations showed that difficulty in obtaining public transportation was a large barrier to changing behavior (Hassan et al. 2017). Research to determine perceived external barriers among the target population is necessary to understand what types of training and interventions are needed (Weinstein 1988). In addition, Weinstein et al. (2008) suggested the use of cues to action such as "how to" guides being most important to distribute after individuals decide to act. If how to guides or detailed instructions are not available, then offering coworkers or offsite trainers as resources to improve workers' confidence in carrying out the intended actions, could go a long way to technology adoption and use (Ajzen, 1991).

Similarly, outlining the costs and benefits of technology use is important to individuals in Stage 5 of the PAPM because, although they have decided to use the technology, it does not mean barriers to use and malfunctions will not occur. Typical of other health theories, if mineworkers can see that the costs outweigh the benefits, their use is likely to move into Stage 6 and 7 (Janz and Becker 1984). Because mining occurs in such a dynamic environment with new hazards emerging daily, it is critical that several external barriers, whether perceived or not, are addressed. Researchers (Scharf et al., 2001) have brainstormed about and developed dynamic hazard typologies to help enhance the interactions of the environment and behavior. Such typologies could easily be modified for specific job positions or tasks that are required to use technology on an ongoing basis.

One method previously used to improve skills-based training and on-the-job experience is the use of Job Training Analysis (JTA) (Wiehagen et al. 2006). These authors note the difference between on the job training and JTA; the latter adds structure in skill transfer via learning from experienced workers, engaging in safety observations, and participating in detailed discussions about the environment and associated tasks being performed. If key concepts of JTA are followed, the potential for not only understanding the risks associated with one's job, but also skill enhancement and confidence, seem likely to improve. To that end, mine sites may benefit from using subject matter experts to create a training roadmap for new technologies that are introduced on their respective sites in order to establish acceptable and unacceptable risks and increase user adherence. Wiehagen et al. (2006) provide sample worksheets and evaluation forms of such a method for several mining occupations that could be referenced and adapted to account for the integration technology and possible effects on previously validated job tasks. If the JTA approach is not achievable, a similar method of peer-to-peer training and intervention can be empowering and help sustain behavior change (Haas and Mattson 2015). It is important to note that, although some participants appeared to be in Stage 6 or 7 within this study, no one reported fully adopting and happily using these technologies to mitigate their risks. In other words, when asked during the interview or focus group to identify their stage, no one reported Stage 6 or 7, *yet*. Therefore, much can still be done, including the aforementioned examples, to help prompt workers' progressing in their stage algorithm.

Intervening at Stage 4

Of the 21 miners who participated in the current study, nine were in Stage 4 of the PAPM, deciding they did not want to or would not use the technology. Out of these nine, six miners had used the technology they were being interviewed about and three had not. As previously discussed, of the three who had not used the technology but had already made up their mind to not use it, they often shared malfunctions or inaccuracies about the technology that they had heard about from another local mine site. These results show the importance of organizational leadership intervening at Stage 3 to proactively transfer accurate and in-depth knowledge to their workforce well before the technology arrives on site. Previous research has shown that negative information dissemination about technology before it is in the hands of end users can stop workers' adoption and appropriate use of the devices (Fischhoff et al. 1993; Wahlström 1992). Likewise, it is important to keep abreast of the negative communication around the technology and proactively address these concerns with miners through things like the JTA described above to help overcome predisposed barriers. Realistically, engaging in these intervention and training activities mentioned could help minimize miners moving to Stage 4, deciding not to act, before even using the technology.

However, for the miners who had used the technology and decided not to integrate the devices into their job tasks, progressing into a phase of adoption could be much more difficult. Participants in the current study expressed that they were not "prepared" or "warned" about the possible inconsistences in the technology, which further halted their desire to use the device. In response, for people who are in Stage 4 of the PAPM, interventions and training that focus on building skills would be futile. Rather, for those who have decided not to act, management must probe further beyond the basic malfunctions of technology and determine if other external pressures, whether social or perceived, exist (Whitcomb et al. 2017). These researchers found that social pressures often exist for youth as they transition through stages of the PAPM or similar theories. Therefore, it is plausible to assume a similar groupthink mechanism among mining crews on the job.

In this sense, using coworkers or mine crews as a way to communicate with, train, and help develop the skills of their coworkers, may be useful in getting out of Stage 4 into Stage 5 and eventually full adoption. However, if any sort of internal or external pressures exist to learning and using new technology, there are several risk-perception variables that were revealed in the current study and are also supported within previous research (e.g., Skinner et al., 2015). Some of these include personalizing risk based on an individual person's behavior; making perceived susceptibility more consistent with the individual's actual risk; and specifying consequences of risk.

Specifically, miners who were in Stage 5 (technology acceptance) indicated that they would use anything that would minimize their risk to health diseases after working in mining for several years. Communicating these messages to younger miners, who may not feel as susceptible to injuries and illnesses, may be a missing piece to embracing these protective technologies. Therefore, this study demonstrates support for increased communication about the likelihood and severity of the health and safety risks that the new technology is trying to minimize.

Limitations

This research is not without limitations. First, the sample is small and limited to the mining industry and, as a result, cannot be generalized to the entire industry or other high-risk industries experiencing increased technology and automation integration. However, the qualitative results did produce consistent feedback about each technology and from workers and/or managers, indicating that the data can be used to further probe these issues in occupational health and safety. Also, the interviews and focus groups only discussed three technologies while new methods of technological innovation are introduced daily. Although the technologies chosen were similar in “age” to the mining industry, feedback about additional technologies may have added to the depth and breadth of the results.

Conclusions and Future Study

This study, although small in scope, enhanced the use of public health theory while also beginning to forecast critical issues regarding technology integration in the near future. First and foremost, the results confirm theoretical research using the PAPM as a stage model that can help bring more attention, awareness, and response to safety and health hazards in the workplace. Historically, stage theories, such as the Transtheoretical Model (TTM) have shown difficulty in reaching high-resistance groups (Weinstein 1988; Weinstein et al. 2008). However, results from this study were able to glean qualitative data that allowed for the identification of determinants for change, which can be applied in future scenarios to mineworkers or mine sites when introducing a new technology or work process. Specifically, results from this study have the potential to help impact workers’ movement from Stage 3 to Stage 5.

First, this study confirmed other research in that awareness and susceptibility of risks in addition to tailored communication can highly influence workers’ movement between early stages of the PAPM, prior to making a decision to act or not (Weinstein & Sandmand, 2002). If miners do not have an accurate sense of their own risks on the job nor the skills to mitigate hazards, adoption of such technologies are also likely to take longer and seem unnecessary to them. Therefore, if managers on a work site know that their miners feel invincible on the job, have a higher tolerance for risk, or overestimate their abilities by doing certain tasks alone, then management should know to proactively address these issues through interventions using assessment technology or risk-based training on the job.

Other research has called for the development of campaigns and interventions to emphasize behaviors where knowledge and awareness is low (Blalock et al. 2016) which appears to be in Stage 3 when individuals have heard of a technology but are undecided about it. Therefore, interventions that focus specifically on individuals in Stage 3 of the PAPM appears to have a likely impact on behavior change. Qualitative results from this study support the use of increased knowledge-based communication and skill-building through job training analyses with crews and managers when introducing new technology. In particular, participants who possessed self-efficacy toward using the technology in question were more likely to communicate their intent to use the technology.

Coupled with this, however, is the need for accurate skill-based training. To demonstrate, one worker said, “If they framed the technology as a learning device and not a safety device, I would be more receptive to learning how to use it and responding.” Proactive, consistent, and realistic communication with end users is imperative so they understand the purpose and function of the technology. In addition, previous safety and health training reviews (e.g., Robson et al., 2007) have shown that the quantity of trainings, or interactions, are important to building knowledge and motivating behavior change. In response, not only explaining the purpose of technology specific to personal protection, but also increasing the quantity of detailed training or casual how-to Q&A sessions with miners, may minimize their perceived, external barriers.

The results also revealed other implications for messaging to move miners from Stage 3 to Stage 5 or for those who have progressed to Stage 5 of the PAPM. For example, participants expressed during interviews that they have little control over many mine site hazards. Previous research has shown that target populations can become frustrated when a risk in which they have no control is compared to a risk in which they do (Visschers et al. 2007). Alternatively, research has shown that if individuals have guidance and are encouraged to analyze their new workload, work tasks, and acquire the necessary knowledge with the inclusion of technology, then initial at-risk decisions are less likely to occur (Wong and Blandford 2001). Therefore, teaching appraisal skills to help miners detect hazards related to their own risk and safety management and how they can solve problems can significantly improve personal efficacy and outcomes (Bartholomew et al. 1993). In response, focusing on job analysis training and tasks similar to the worksheets developed by Wiehagen et al. (2006) to provide miners with autonomy and control over some risks is a promising addition when determining messaging with individuals who are in Stage 5 of the PAPM.

Second, this study is at the forefront of showing a possible pattern in progressing through PAPM stages based on time and experience using technology. Results show the apprehension of technology in the initial months or year of introduction at a mine site, with several participants in the “no” stage of technology adoption. Eventually, after barriers encountered are fixed and systems function consistently, end users have a better perception and appreciation for the technology. However, the use of the PAPM illustrated the existence of a lengthy integration period which can prevent miners from doing their job as safely and effectively.

Finally, this study demonstrates the application of using qualitative methods in stage theories to better identify the accurate PAPM stage of individuals as well as barriers to stage progression. Most studies that utilize stage change theories do so using sophisticated quantitative methods to determine potential confounding relationships in stage progression (e.g., Barnard et al. 2017). Although most studies acknowledge the greyness between stages in their results (Weinstein 1988; 2008), they offer little insight in how to better identify the internal and external factors that contribute to these vague gaps in future research. However, the use of qualitative methods helped shed detailed insight and patterns in adopting and deciding why or why not to act on specific safety and health information. In doing so, this study has the potential to further the application of stage models in behavior change research within occupational safety and health.

Additional research and recommendations are needed to help inform and sustain safe and consistent use of technology. However, this research points to trends in adoption processes and methods to minimize identified barriers to technology acceptance and adoption in the mining industry, providing possibilities for tailored interventions and on the job training. Most importantly, it speaks to the undeniable issues that organizations will have when initially incorporating something new with workers in a high-risk industry such as mining. This paper begins to fill in some of these gaps between various stages of decision making and future research should continue this line of work to contribute to the development of appropriate risk management practices, including job-specific interventions, training, and evaluation to mitigate potential issues that end users have with technology in the workplace.

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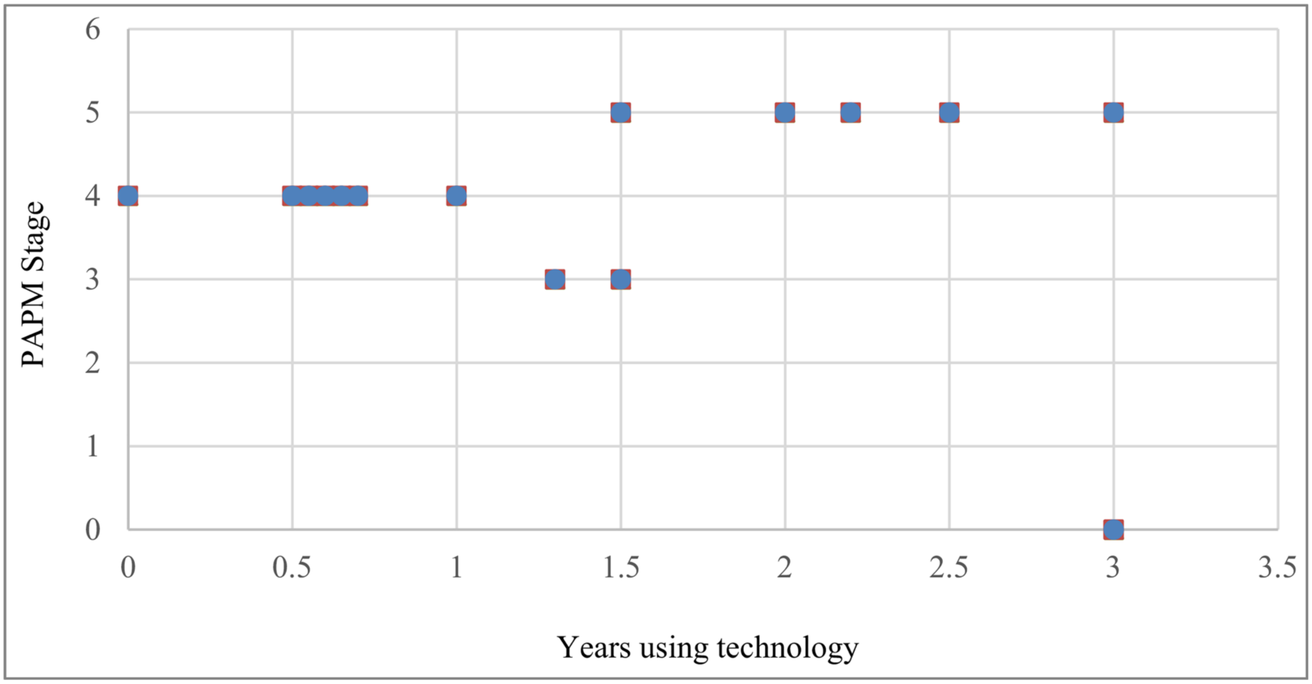

Fig. 1.
Time using Technology in years (x) and Current Stage of PAPM (y)

Table 1

Constructs of the Precaution Adoption Process Model (adapted from Weinstein et al. 2008)

PAPM Stage	Process in Adoption
1. Unaware of the potential issue	If people have never heard of the hazard or accept the potential risks, they do not have formed opinions about the proposed solution(s).
2. Unengaged by issue.	People have learned about the hazards and proposed solution but have not considered whether they need to do anything about it.
3. Undecided about acting	The decision-making stage, where people have become engaged and are considering their response.
4. Decided not to act	Halting the adoption/behavior change process.
5. Decided to act	Deciding to adopt a new precaution/behavior.
6. Acting	Initiating a behavior.
7. Maintenance	Maintaining the behavior over time.

Table 2

Overview of three mine health and safety protective technologies

H&S technology	Overview, purpose, and references	Regulated	Intended commodity	End user(s), intended use or regulated use
Helmet-CAM assessment technology and Enhanced Video Analysis of Dust Exposure (EVADE) software	The Helmet-CAM system is used to identify higher sources of respirable dust and other contaminants. The technology includes a lightweight video camera on the hardhat and an instantaneous dust monitor on a belt/backpack. Miners perform their job tasks as video and dust exposure data are collected. Video footage and dust data then are downloaded to NIOSH-developed EVADE software. The software merges the camera footage and dust data to produce a video that can be played back to identify work areas and tasks that cause higher respirable dust exposures (see Cecala and O'Brien 2014; Cecala et al. 2013; Cecala and O'Brien 2014; CDC, 2014).	No, but there are regulations that state how much respirable dust a miner is allowed to be exposed to during an 8-h shift.	Surface metal/non metal	Workers wear the sampling technology (around 4.8 pounds) approximately two hours of an eight-hour shift to find peak dust points. Managers download the information onto their computers with the downloaded software to review high dust exposure tasks and scenarios.
End of shift silica sampling	The end of shift silica monitoring technology combines the current practice of collecting respirable dust samples for silica analysis, but rather than sending the samples to MSHA for analysis that takes about six weeks, a portable instrument is used to immediately determine the silica collected in each sample after the shift ends (see Cauda et al. 2016).	No, but there are regulations that state how much respirable dust a miner is allowed to be exposed to during an 8-h shift.	Surface and underground coal, metal, and nonmetal	Workers wear the sampling technology (around 1.8 pounds) during a designated sampling period for a full shift. Whoever is in charge of dust sampling opens the plastic portion of sampling cassette and inserts the filter cartridge in the compartment of the portable silica instrument. An end of shift sample is retrieved.
Proximity detection systems	The PDS was developed in response to a regulation passed by MSHA to keep miners out of "red zones" or dangerous areas. The technology determines a miner's position relative to a specific piece of machinery and sends an alert to the miner to change positions if needed. If adhered to, the technology can prevent collisions between vehicles, vehicles and mineworkers, and vehicles and infrastructure (see Bartels et al. 2009; Ducarme et al. 2013; Haas and Rost 2015; Schiffbauer 2002).	Yes, regulation took effect on March 16, 2015 that all continuous mining machines in underground mines must have this technology.	Underground coal	Certain job roles are requested to wear a component or device for their complete shift to protect against changing hazards. The device (around 1 pound) measures the magnetic field around them and provides the operator with a warning sound, and eventually disable, if they are too close to the machine. Information is not stored, just reacted to in real-time on the job.

Table 3

Precaution Adoption Process Model – Stage Classification Algorithm for Mine S&H Technology (adapted from Weinstein 1989; Weinstein et al. 2008)

First, let me document your current use of the [technology].	
1	Have you heard of [technology]? • No – STAGE 1 • Yes [Go to 2]
2	Have you used [this technology for your job]? • Yes [for how long? Continue to probe] • No [Go to 3]
3	Which of the following best describes your thoughts about using [technology for your job]? • I've never thought about this issue – STAGE 2 • I'm undecided about [this technology] – STAGE 3 • I've decided I don't want to use [this technology] – STAGE 4 • I've decided I do want to use [this technology] – STAGE 5
4	You just said you do/do not want to use [this technology]. Why do you feel this way? – Distinguish STAGE

Table 4

Participant PAPM Stage Algorithm Results

PAPM Stage	Total Worker	Worker acceptance breakdown by technology use	Total Manager	Manager acceptance breakdown by technology use
STAGE 2: I've never thought about this issue	0	N/A	1	Not used technology: 1
STAGE 3: I'm undecided about [this technology]	7	Used technology: 3	1	Not used technology: 1
		Not used technology: 4		
STAGE 4: I've decided I don't want to use [this technology]	9	Used technology: 6	0	N/A
		Not used technology: 3		
STAGE 5: I've decided I do want to use [this technology]	5	Used technology: 5	17	Used technology (only testing of, not regular extended use: 17
	21	Not used technology: 0	19	Not used technology: 0